of the spectral flash by the white flash, a short interval of darkness between them being preferable to the smallest overlap. For this reason the shaft is fitted with a screw nut, which being slackened, the angular position of the slits with respect to the sectors can be accurately adjusted. On rotating the discs steadily, but not too quickly, a spectrum of complementary colours is seen with the greatest distinctness. By placing a narrow strip of black card across the mouth of the scale tube, a portion of the white flash may be stopped out, allowing the normal spectrum to be seen in that part of the field. It is necessary, however, to shade the corresponding part of the slit somewhat, so that the normal spectrum may not overpower the complementary spectrum. The colours as I see them are as follows:—Red is replaced by Prussian blue, green by purple (a red shade of Hoffmann's violet), blue by orange, and violet by yellow. To show the complementary of violet it is necessary to use sunlight, or, better still, the arc light. I have never been able to see it properly by any of the methods involving the use of white card or paper surfaces as reflectors.

The experiments of Section 3, for which a wide dispersion was required, were made with a large direct-vision spectroscope belonging to the Marlborough Collection, for the use of which I am indebted to the Aldrichian Demonstrator of Chemistry, Mr. W. W. Fisher. I have also to thank Professor Gotch for the use of the electric light in the physiological laboratory. The remainder of the work was done at Reading College, and the expenses have been defrayed by a portion of the sum of £10 allotted to me by the Royal Society out of the Government Grant.

"On the Production of Artificial Colour-blindness by Moonlight."

By George J. Burch, M.A. Oxon., Reading College, Reading. Communicated by Professor Gotch, F.R.S. Received January 30,—Read February 8, 1900.

Since the publication of my paper on "Artificial Colour-blindness"* I have found a very general and not unnatural tendency to regard the results described therein as phenomena of a pathological condition induced by the severe strain to which the structures of the eye had been subjected. In my paper I indicated, perhaps too briefly, that this could not be the case, since "the same general phenomena are observable alike with strong sunlight and with the faintest light the eye is capable of perceiving."

The purpose therefore of the present communication is to describe some of the experiments on which that statement was based.

* 'Phil. Trans.,' B, vol. 191 (1899), p. 1.

When green-blindness is induced by exposure of the eye to intense green light, not only is the observer unable to perceive the colour of green objects, but the sensation of green is no longer excited by the intense green light that caused the blindness. And the same may be said of blue-blindness. On the other hand, with artificial red-blindness the exciting light still looks reddish, though greatly dulled and much paler in hue, but all objects less brightly illuminated fail to excite the red sensation. Probably in the case of green-blindness the green sensation is not entirely destroyed, but reduced so much that the red and blue sensations, which are also excited by that same part of the spectrum, completely overpower it. In producing red-blindness, as there are no colours to the left of red, I have generally used a part of the spectrum which excites only the red sensation, and which therefore must continue to appear red if visible at all. But I have not thought it desirable to push the fatigue of the retina far enough to destroy the sensation of light.

For the mere demonstration of the phenomena of colour-blindness, light of quite moderate intensity is amply sufficient if the precaution is taken of shielding the eye from all other light during the experiment, and of giving it time to recover from the effects of previous illumination. The colour-blindness so produced is, however, not absolute, but merely relative, the sensation which has been fatigued, whether red, green, blue, or violet, being still excited by a stronger stimulus.

The following is perhaps the most striking and suggestive way of making the experiment :—

1. I exposed my left eye to direct moonlight in the focus of a lens behind a screen of ruby glass combined with a gelatine film stained with magenta. After three minutes I looked through a spectroscope directed to the moon. The red had entirely disappeared, and only the green, blue, and violet were visible. With the right eye I could see the red as well as the other colours.

2. I exposed my right eye in the same manner to moonlight, using a screen of green glass instead of the red. On looking through the spectroscope I found the green sensation had entirely vanished, the red meeting the blue in the same part of the spectrum, viz., between E and *b*, as in my experiments with sunlight.* The violet was easily distinguished from the blue in this case also. The left eye was still partially red-blind, and the contrast between the spectrum as seen by it and by the right eye was very marked.

I was unable to use spectral colours for fatiguing the eye because the full moon is not visible at this season of the year from the laboratory in which the large spectroscope is mounted, and the intensity of the light was too much reduced by reflection from the two mirrors of the

* 'Phil. Trans.,' B, vol. 191, Plate I, figs. 4 and 5.

heliostat. I did not therefore make any observation with blue or violet light.

As may be imagined, it is necessary to use a larger lens with moonlight than with sunlight. In practice I have found an ordinary reading lens, of 4 inches diameter, sufficient. To obtain the full intensity of illumination, the focal length should be such that the moon's image may be not smaller than the pupil of the eye.

There are two points of interest in connection with this experiment. The first is that the illumination of surrounding objects is on the same scale, as regards contrast of light and shade, in moonlight as in sunlight—that is to say, in each case the source of light is an object subtending an angle of about 30′ at a distance which is practically infinite. Whatever difference may seem to exist must be of physiological or psychical origin. The deeper shadows in moonlight probably afford too little stimulus to fully excite the sensation of vision even in an eye accustomed to darkness; but it must not be forgotten that we accentuate this difference by a habit of looking at the moon itself and at the bright sky near it, thus blinding ourselves to the faintly illuminated details of the shadows. If we were to do the same with sunlight the shadows would seem equally lacking in detail. In a room artificially lighted there is seldom so much contrast between lights and shadows. Light-coloured objects are usually to be found in close proximity to the lamps, even where white shades or globes are not used to diffuse the light. It is less easy to demonstrate the phenomena of temporary colour-blindness under these circumstances, owing to the greater relative intensity of the dazzle-tints* resulting from the action of the diffused light before the experiment began. Until these are gone the retinal fatigue is not confined to one colour. If in experimenting with moonlight the observer accidentally looks at the moon's disc before his eye is protected by the coloured screen, a well-defined after-image is produced, and the subsequent phenomena of colour-blindness are only locally modified, whereas if an after-effect even of less intensity, due to diffused light, is present, the colour-blindness may be to a great extent masked.

The other point of interest in connection with this experiment is that colour-blindness has been produced by light no stronger than that reflected by ordinary pigments in sunshine. That this is so is evident if we look at the moon's disc in the daytime through the same red glass and lens and compare it with a piece of coloured paper. It can therefore be hardly maintained that the condition of temporary colour-blindness should be regarded as a pathological result of excessive stimulation of the colour sensations. Merely to look for a few seconds

* It will be convenient, in describing my own experiments, to retain this word, which I have used to signify the "elementary component sensations of the positive after-effect." 'Phil. Trans.,' B, vol. 191 (1899), p. 6.

at a scarlet poppy in a cornfield causes a measurable degree of red-blindness for the next two or three minutes. In applying the spectroscopic method of measuring the colour sensations described in my previous paper* it is necessary to guard against this source of error. Last summer I had a case of a man who seemed at first to be very nearly green-blind. His green sensation did not reach more than half way between *b* and F, even after fatiguing for thirty seconds with blue light, and it was correspondingly shortened on the red side. After conversing with him for some time in the subdued light of the laboratory I repeated the measurements, and found that his green sensation then extended considerably beyond F. It appeared that he had been strolling about the Parks on the grass in the bright sunshine. I have myself frequently experienced a temporary green-blindness from a similar cause. The effect seems to be intensified by looking at a white surface, as, for instance, in reading a book while sitting on the grass. After a time the green leaves seem to lose their colour and become greyish. This effect may be often noticed during a long walk through the fields. If during this condition the eyes are directed to a small red spot on a black surface, as, for instance, a single geranium petal on the black cover of a book, and the observer walks with it quickly into a dark shed or barn, the colour of the geranium petal will seem to change from red to orange and then to yellow, and finally almost whitish, owing to the subjective admixture with the red of the green dazzle-tint. On coming out into the light again the red colour will reappear. These changes are similar to those observed in the red end of the spectrum during green-blindness on opening and closing the slit;† and as the experiment requires no apparatus, I have recommended it in my lectures for the last two years.

The retinal fatigue induced by white light under various conditions forms the subject of a recent paper by Beck.‡

* 'Phil. Trans.,' B, vol. 191 (1899), p. 19.

† 'Phil. Trans.,' B, vol. 191 (1899), p. 8, and Plate I, figs. 4 and 5.

‡ Archiv für die ges. Physiologie,' vol. 76, p. 634.